Last Time

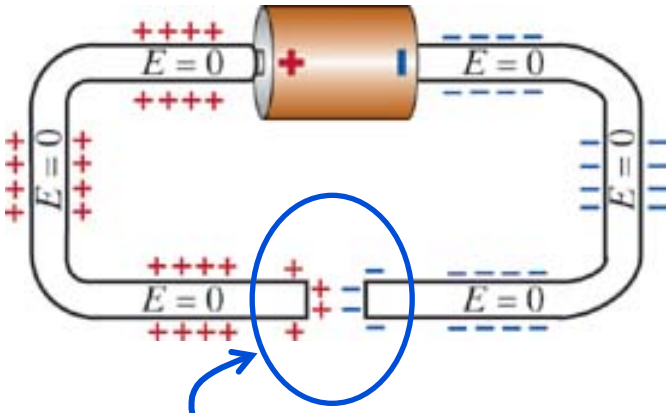
- Transient response when connecting a circuit
- How long until steady state is reached?
- Introduction to Resistors
- Energy conservation in a circuit
- Kirchhoff's Voltage Loop Law
- Batteries

Today

CAPACITORS.
Lots of Capacitors.

Connecting a Circuit

What happens just before a circuit is connected?



Think about the gap...

Before the circuit is connected:

- No current flows $I = |q|nAu|\vec{E}| = 0$
- System is in ***equilibrium:***

$$\vec{E} = 0$$

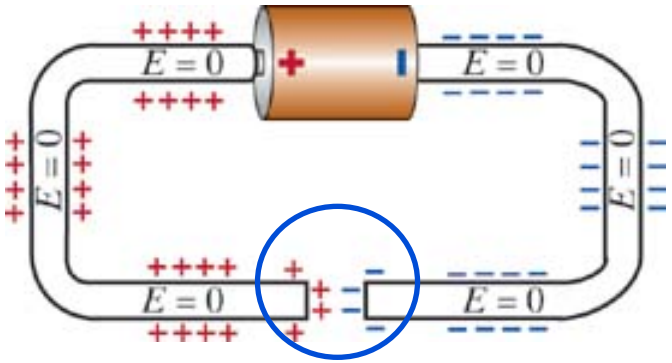
$$\bar{v} = u|\vec{E}| = 0$$

- Charge on faces of gap

Blast From the Past Lecture 15

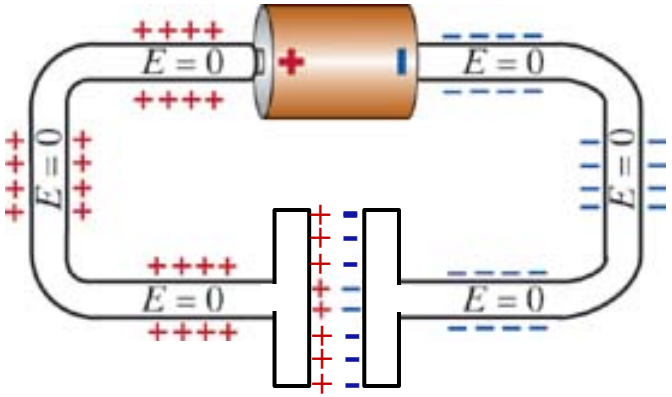
Building a Capacitor

Add plates at the gap



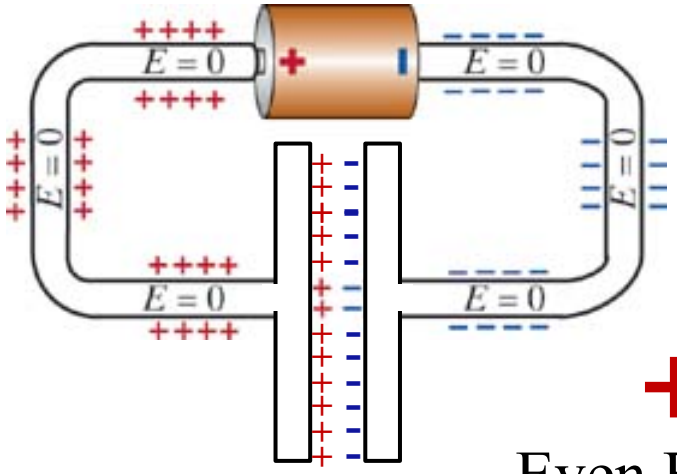
+Q -Q

Gap Charge



+Q -Q

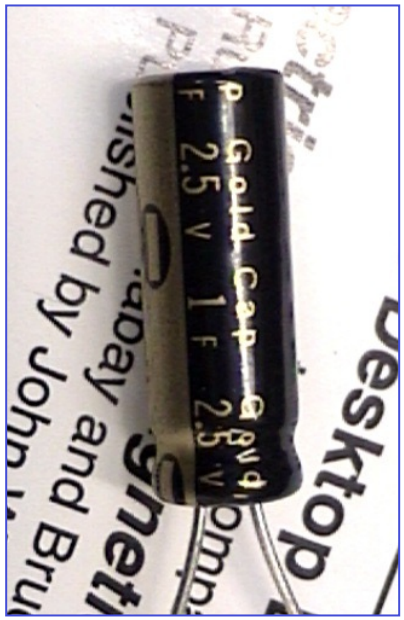
Bigger Gap Charge

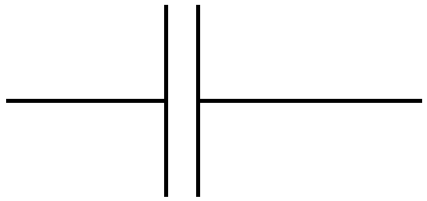


+Q -Q

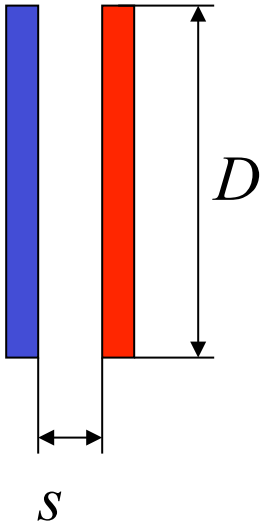
Even Bigger Gap Charge

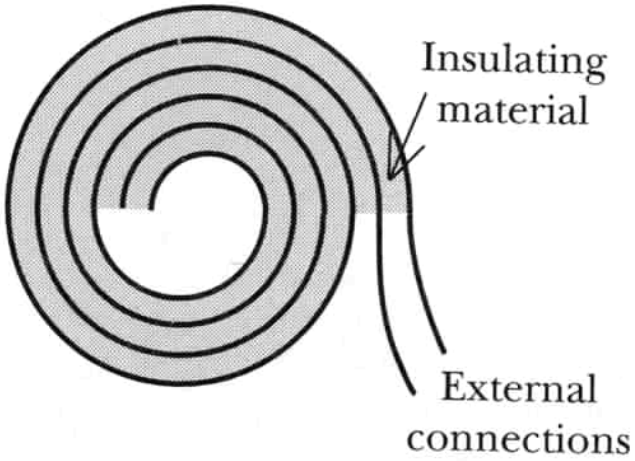
Capacitor: Construction and Symbols



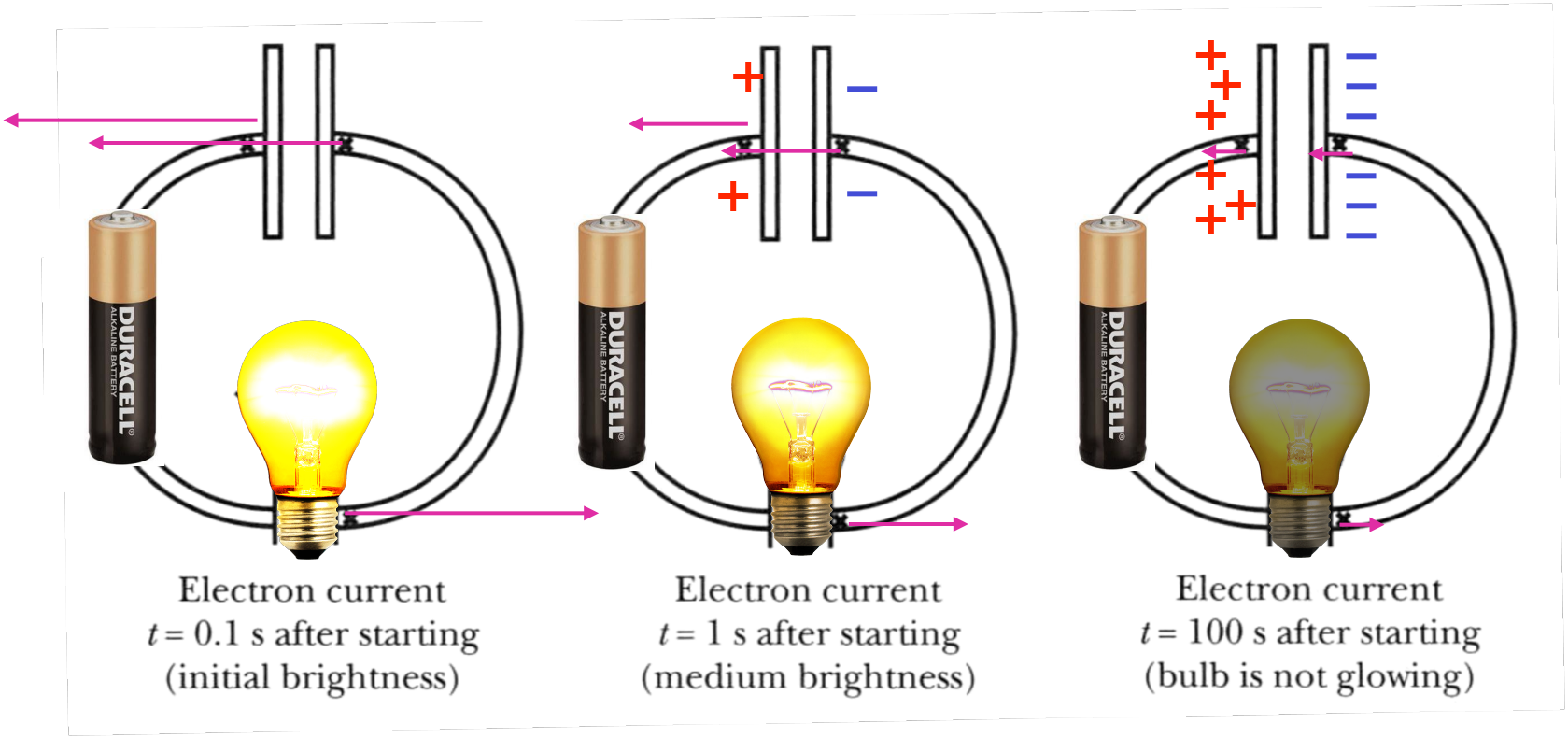


Circuit Symbol





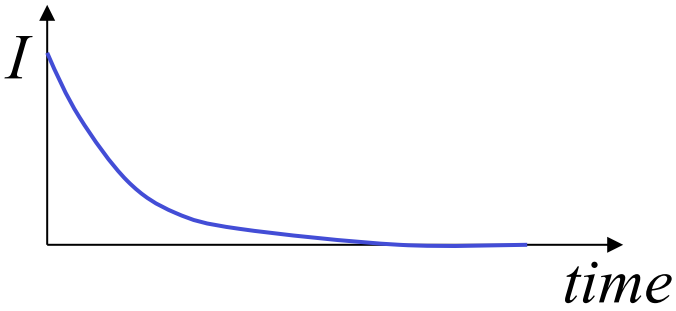
Capacitor: Charging

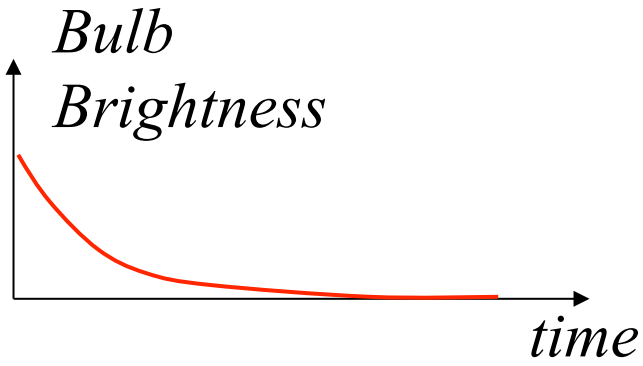


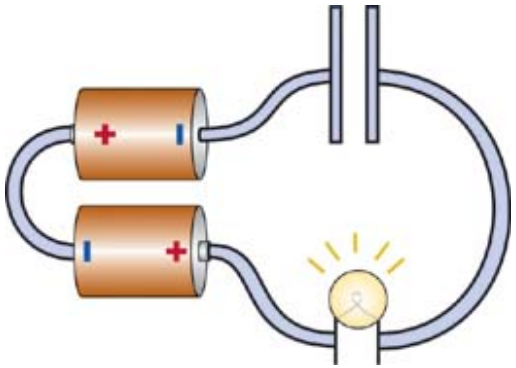
Current flows into & out of capacitor, but not through it.
Charges build up on capacitor until current finally stops. (~ 10 sec)

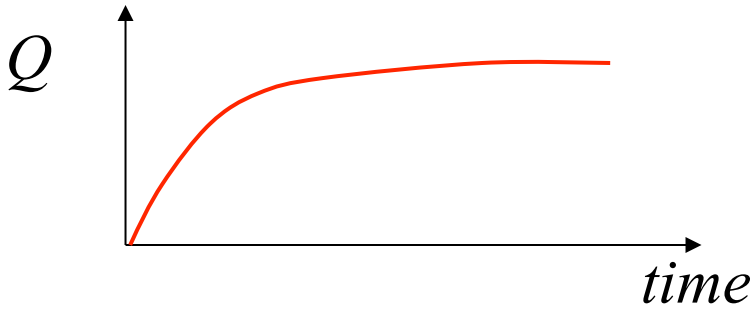
Fringe field of a capacitor rises until E=0 in a wire – static equilibrium.

Charging Capacitor









Capacitor: Charging

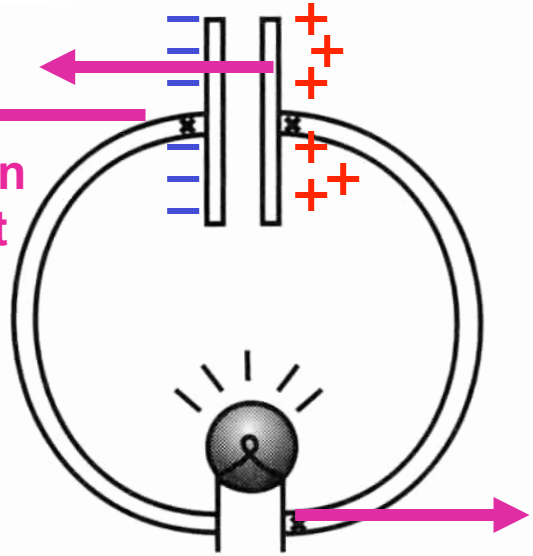
Why does current ultimately stop flowing in the circuit?

Ultimately, the fringe field of the capacitor and the field due to charges on the wire are such that E=0 inside the wire. At this point, i=0.

Capacitor: Discharge

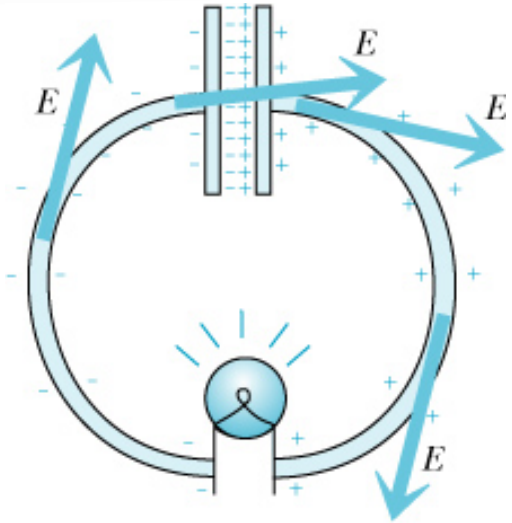
Start with a charged capacitor

Electron Current



Electron current
$t = 0.1$ s after starting
(initial brightness)

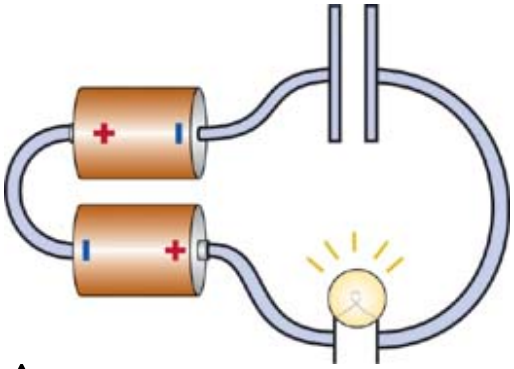
Electric Field

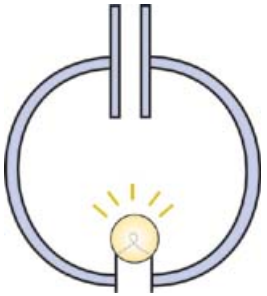


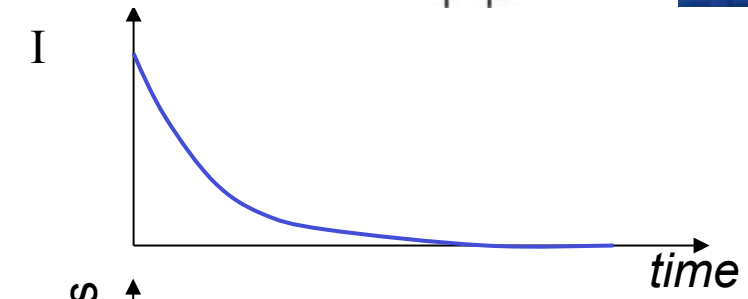
Charging

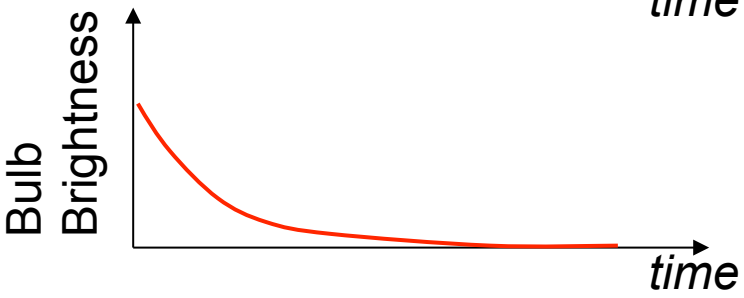
"One of these things is not like other"

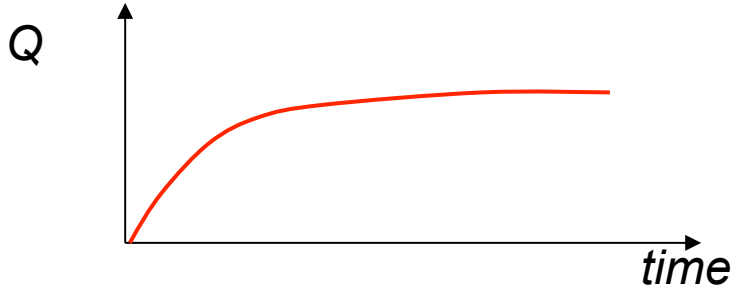
Discharging

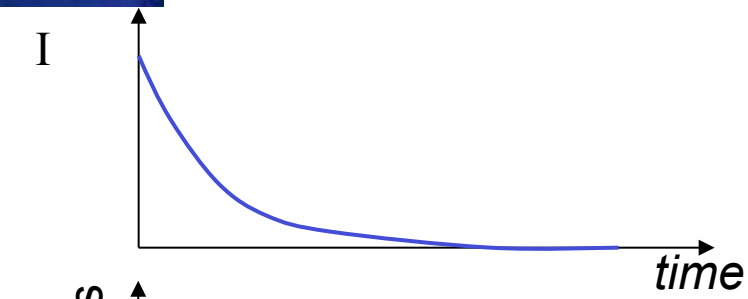


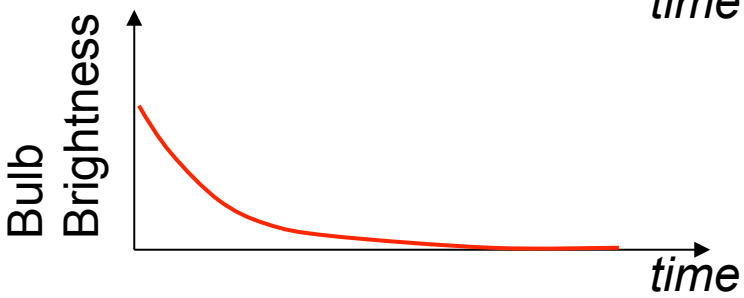


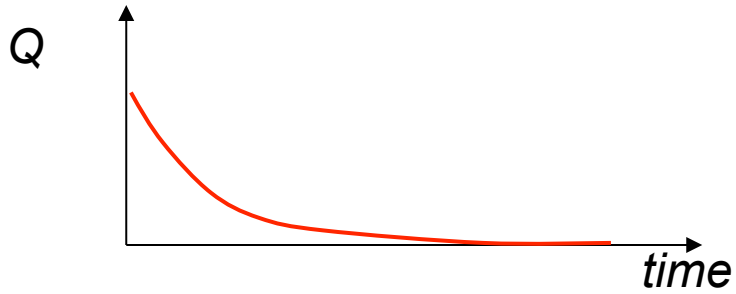




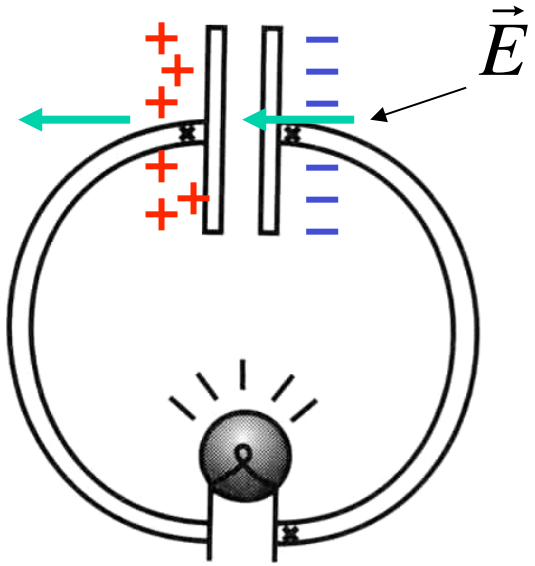








How is Discharging Possible?



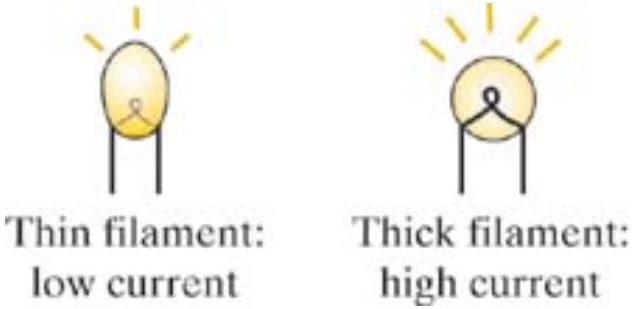
Positive and negative charges are attracted to each other: how can they leave the plates?

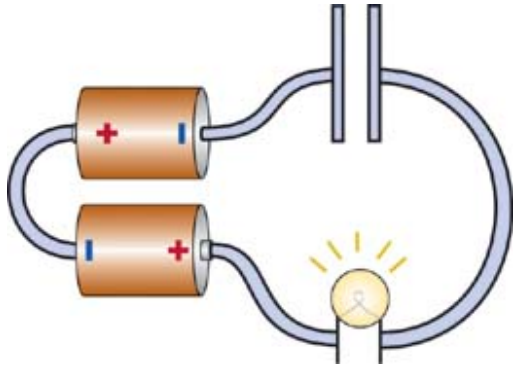
Two ways to think about it:

Opposites attract, but the like charges are repelling more

Fringe field is not zero

The Effect of Different Light Bulbs





Which light bulb will glow longer?

1) Thick filament is brighter → capacitor gets charged more?
2) Thin filament glows longer → capacitor gets charged more?

In equilibrium:

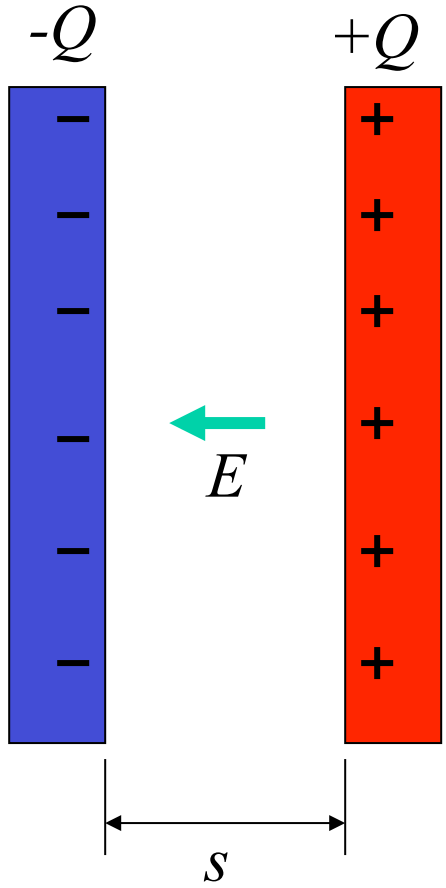
Voltage across capacitor = Voltage across battery

Capacitor charged by same amount in both cases.

Definition of “Capacitance”

$$Q = C|\Delta V|$$

Mnemonic Device:
“Quacks are CoVered”
(by medical insurance)



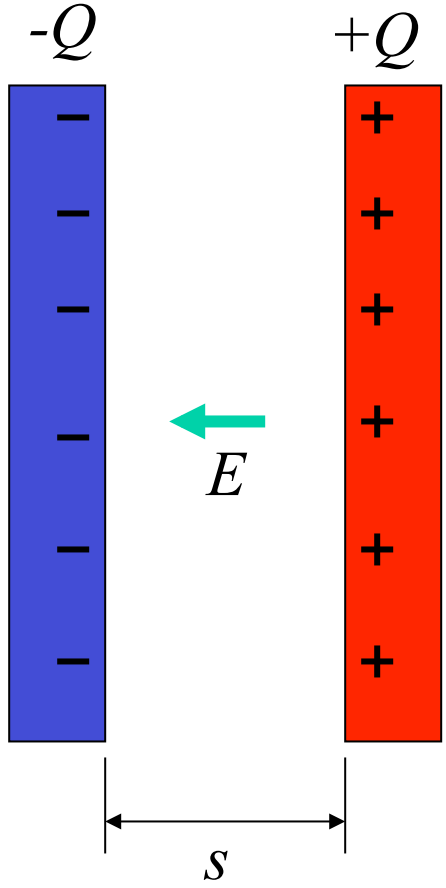
Capacitance

$$Q = C|\Delta V|$$

Electric field in a capacitor: $E = \dfrac{Q/A}{\varepsilon_0}$

$$\Delta V = -\int_i^f \vec{E} \bullet d\vec{l} \longrightarrow |\Delta V| = Es$$

$$|\Delta V| = \frac{Q/A}{\varepsilon_0} s \longrightarrow Q = \frac{\varepsilon_0 A}{s} |\Delta V|$$

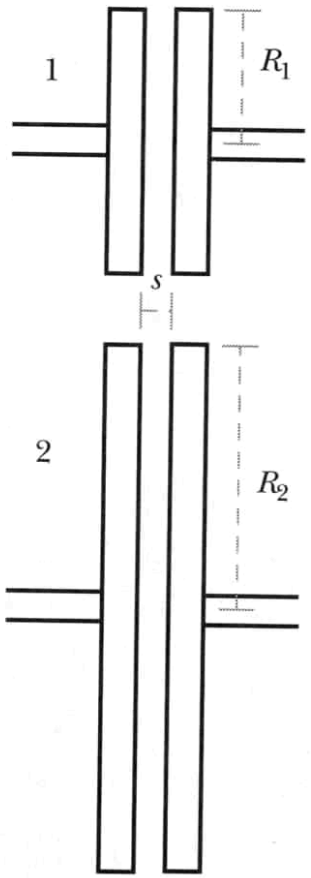


Capacitance of a parallel-plate capacitor: $C = \dfrac{\varepsilon_0 A}{s}$

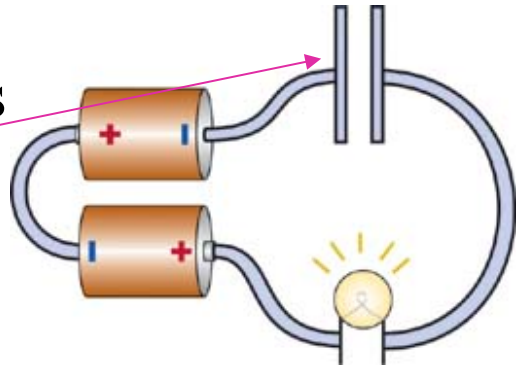
iClicker

Effect of the Capacitor Disk Size

$$Q = \frac{\varepsilon_0 A}{s}|\Delta V|$$



Use two different capacitors in the same circuit

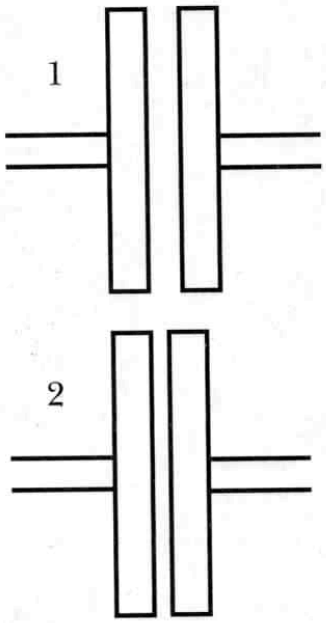


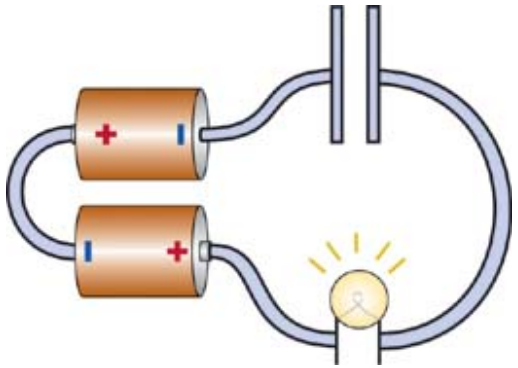
After charging, which capacitor holds more charge?

Charge the capacitor, then delete the batteries:
Which capacitor runs the bulb longer?

Effect of the Capacitor Disk Separation

$$Q = \frac{\varepsilon_0 A}{s}|\Delta V|$$

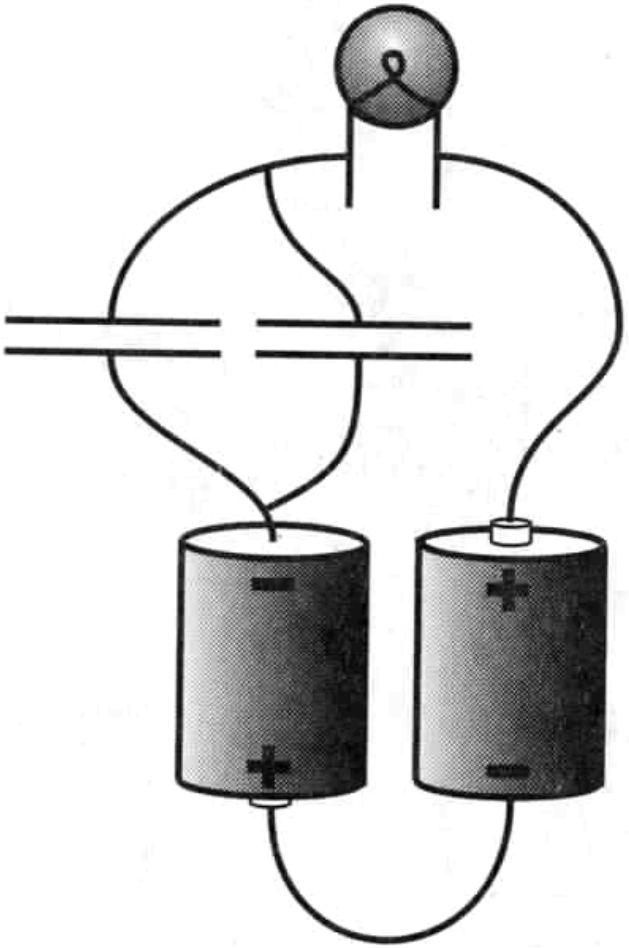




After charging, which capacitor holds more charge?

Charge the capacitor, then delete the batteries:
Which capacitor runs the bulb longer?

Parallel Capacitors

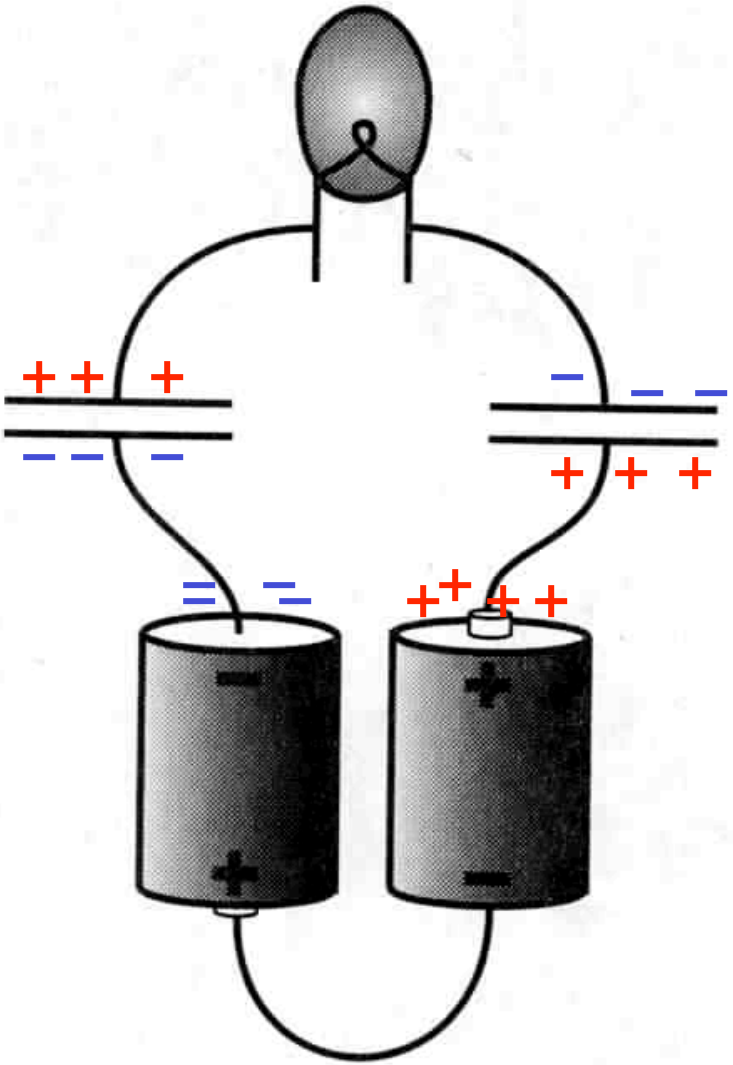


Initial moment: brighter?

Fringe field: $E_1 \approx \frac{Q/A}{2\varepsilon_0}\frac{s}{R}$

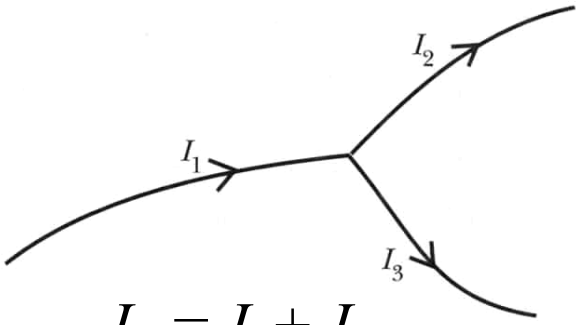
Capacitors in parallel effectively increase A

A Seemingly Isolated Light Bulb



Will it glow at all?
How do electrons flow through the bulb?

The Current Node Rule in a Capacitor Circuit



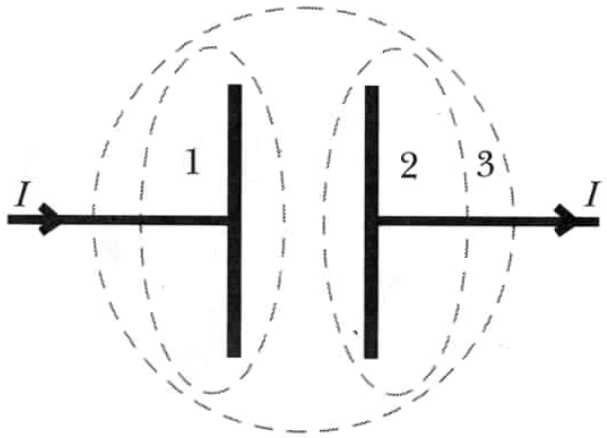
$I_1 = I_2 + I_3$

Charge conservation:

$$\sum_i I_i = 0$$

$I_i > 0$ for incoming
$I_i < 0$ for outgoing

…in steady state



Capacitor transients:

not a steady state!

Cannot use Kirchhoff rule for a part of a capacitor (area 1 or 2)

But can use for capacitor as a whole (area 3)

A Capacitor With an Insulator Between the Plates

No insulator:

$$E = \frac{Q/A}{\varepsilon_0}$$

$$|\Delta V| = Es$$

$$|\Delta V| = \frac{Q/A}{\varepsilon_0} s$$

$$Q = \frac{\varepsilon_0 A}{s} |\Delta V|$$

$$C = \frac{\varepsilon_0 A}{s}$$

With insulator:

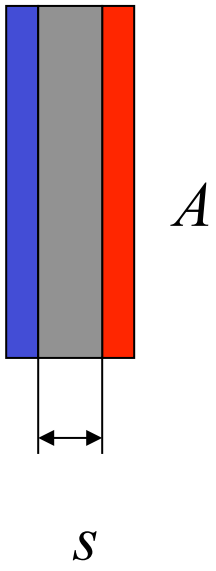
$$E = \frac{Q/A}{K\varepsilon_0}$$

$$|\Delta V| = Es$$

$$|\Delta V| = \frac{Q/A}{K\varepsilon_0} s$$

$$Q = \frac{K\varepsilon_0 A}{s} |\Delta V|$$

$$C = K\frac{\varepsilon_0 A}{s}$$



Today

CAPACITORS.
Lots of Capacitors.